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BGC Project Memorandum

To:	Provincial Emergency Program	Fax No.:	
Attention:	Jim Whyte	CC:	
From:	Matthias Jakob	Date:	December 12, 2003
Subject:	Hatzik Valley Preliminary Debris Flow Hazard Assessments		
No. of Pages (including this page): 17		Project No:	0378.001

1.0 INTRODUCTION AND BACKGROUND

A series of debris flows and high discharge events occurred on October 16 to 18, 2003 on the west-facing slopes of Hatzik Valley and Miracle Valley (Fig. 1). Most creeks along on the west facing slopes of Hatzik Prairie and Miracle Valley are prone to debris flows including Saporano Creek and Pattison Creek, which were not addressed in this study.

Thurber Engineering was retained by the Fraser Valley Regional District to inspect and report on the presence of debris flow hazards in the Hatzik Valley and other areas in the regional district following the mid-October event. The scope of the work was limited to identifying the areas of risk but not quantifying the risk. Helicopter inspection was performed by Thurber Engineering (Thurber) followed by limited fieldwork. Thurber's findings are summarized in letter reports of October 31 and November 7, 2003, and a memo of November 25, 2003 to the Fraser Valley Regional District (FVRD).

Subsequent to the work by Thurber, BGC Engineering Inc. (BGC) was retained by the Provincial Emergency Program (PEP) to:

- provide a preliminary hazard and risk assessment for Field Creek, MacNab Creek, Eng Creek, Carratt Creek and Dale Creek;
- determine if the likelihood to houses being impacted by debris flows has increased since the last events; and
- determine if there are cost effective remediation opportunities to protect the houses and prevent or minimize structural damage from direct impact by debris flows.

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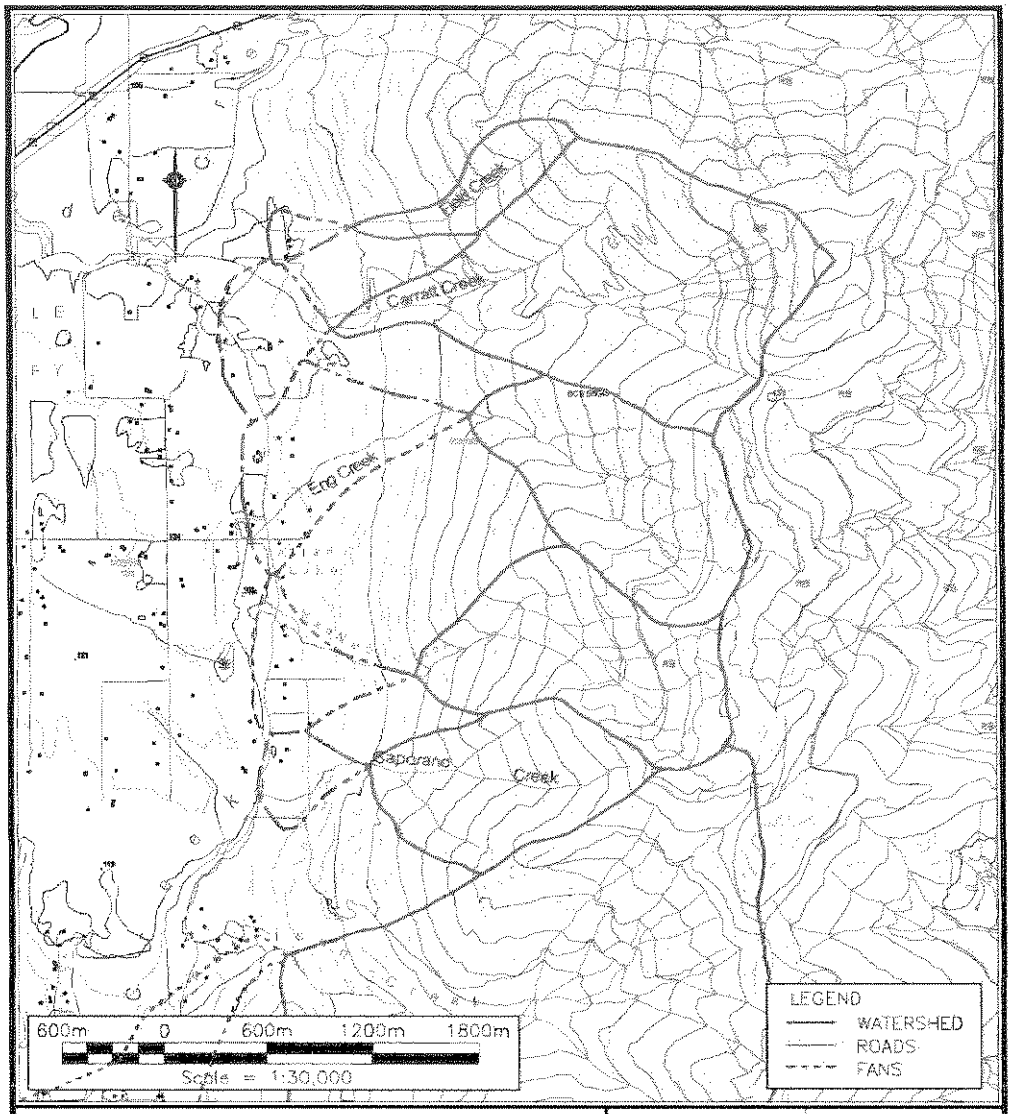
6785-20-20611

The following memorandum provides preliminary results of a field investigation and analyses by Dr. Matthias Jakob, Ph.D., P.Geo. of BGC. More detailed information will be included in a report to be submitted in January 2004.

Figure 1. Study Area. Dale Creek is located further south and will be included in the compendium report issued in January 2004.



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PROJECT: PRELIMINARY DEBRIS-FLOW HAZARD AND RISK ASSESSMENT

TITLE: STUDY AREA

CLIENT:	PROJECT No.	DWG. No.	REV.
PROVINCIAL EMERGENCY PROGRAM	0378-001-01	FIGURE 1	0

0378_001_01_001 Watershed.dwg

2.0 INTENDED USE OF THIS MEMORANDUM

This memo is based on preliminary and is not intended for detailed risk assessment leading to engineered construction nor decisions on public safety. It should only be used to identify the relative degree of hazard and risk on each creek. Reported frequencies and magnitudes may change as more detailed hazard analysis is carried out. Fan boundaries and hazard zones are approximate and should be used to get a general sense of the areas that may be affected in low frequency debris flows. The hazard zones are too inaccurate to be translated in landuse decision as those boundaries may change with a more detailed assessment and computer modelling of debris flows.

3.0 RISK ASSESSMENT METHODOLOGY

This section provides a brief summary of the methodology used to assess hazard and risk posed by debris flows in Hatzik Valley. For the purpose of this study, risk is defined as the combination of hazard and consequence, where:

- *hazard* represents the occurrence of creek events, expressed in terms of probability and magnitude; and
- *consequence* represents the elements at risk and their vulnerability to damage during an event.

This definition reflects the fact that the generation of a risk of concern requires the presence of both a significant hazard and some degree of consequence (often in the form of buildings or infrastructure). A severe hazard in an undeveloped area with minimal potential consequences will result in a low risk. Conversely, a less severe hazard occurring in a developed area may result in a significant risk.

This section outlines the methodology used to assess hazard and consequence, and to combine these two components into a preliminary risk assessment. It will also comment on the decision process of acceptable risk.

3.1 Creek Hazards

Hazard assessment in this memorandum is based on the capability of a particular creek to produce debris flows and does not consider whether the potential creek hazard will affect public safety, buildings or infrastructure. Creek hazard is defined in terms of **probability** and **magnitude**.

3.2 Hazard Probability

The classification system used in this preliminary study is shown in Table 1. Hazard probability is often expressed as a return period, which is the average number of years between event occurrences for an event of a particular magnitude. In other words, a 100-year return period event occurs on average once every 100 years. Smaller events generally occur more often, and larger events generally occur less often. For example, if debris flows have occurred in a creek in 1850, 1910, 1915, 1970 and 2000 one can state that five debris

flows have occurred in a 150-year time period with a return period of 150/5 = 30 years. A frequent misconception by lay people is a 30-year return period means that 30 years will pass until the next debris flow. As evidenced by the 1915 event that occurred only five years after the 1910 event this assumption is incorrect. In fact, certain channel changes may increase in the probability of a recurrent debris flow shortly after the last debris flow.

There are a number of methods available to determine hazard probability, which is explained in the compendium report to be issued in January of 2004. Table 1 provides simplified hazard classifications as both return periods and percent chance of occurrence in 50 years and states the significance of each probability class.

3.2.1 Table 1. Classification of Hazard Probability

Return Period (years)	Qualitative Probability Classification	Probability of at Least One Occurrence in 50 Years	Significance of Probability
< 20	High	more than 90%	The hazard is imminent, and very likely to occur within the lifetime of a person or structure. There will be unambiguous and relatively fresh signs of disturbance.
20 to 100	Medium	40% to 90%	The debris flow is likely to happen within the lifetime of a person or structure. Disturbances are identifiable from deposits and vegetation, but may be overgrown, obliterated by fluvial deposits or eroded.
100 to 500	Low	10% to 40%	The hazard occurrence within a given lifetime is possible. Signs of disturbance such as vegetation damage may be difficult to identify. A probability of 10% in 50 years (475-year return period) is used by the BC Ministry of Transportation as a design standard for natural hazards.

3.3 Debris Flow Hazard Magnitude

Hazard magnitude refers to the size of the debris flow in terms of volume and peak discharge. The event **volume** is the total quantity of sediment transported past the fan apex during the debris flow as measured in cubic metres (m^3), while the **peak discharge** is the maximum rate of flow through a given cross-section expressed in cubic metres per second (m^3/s). In southwestern B.C., debris flow volume and peak discharge are highly variable and depend on watershed area, the amount of erodible debris, channel slope and climatic regime. For a particular creek a different hazard magnitude may be assessed for each probability class. For example, a *high* probability debris flow may be associated with a volume of 5000 m^3, while a *medium* probability debris flow may correspond to a volume of 15,000 m^3. Table 2 provides a size classification for bouldery debris flows as encountered in the study area.

3.3.1 Table 2. Classification of Debris Flow Sizes

Size class	V, Range (m^3)	Q_p, Range (m^3/s)	Potential Consequences
1 (very small)	$< 10^3$	5 - 30	Could bury a car, damage a small building, break trees, block culverts.
2 (small)	$10^3 - 10^4$	30 - 200	Could destroy larger buildings, damage concrete bridge piers, block or damage highways and pipelines, derail trains.
3 (moderate)	$10^4 - 10^5$	200 - 1500	Could destroy parts of villages, destroy large sections of infrastructure corridors, block creeks.
4 (large)	$10^5 - 10^6$	1500 - 12,000	Could destroy parts of towns; destroy forests of 2 km^2 in area, block creeks and small rivers.
5 (very large)	$10^6 - 10^7$	>12,000	Could destroy entire towns, obliterate valleys or fans of up to hundreds km^2 in size, block large rivers

V is the total volume, and Q_p is the peak discharge.

3.4 Debris Flow Probability – Magnitude Relationships

Once the probability and magnitude of debris flows for a given creek has been established, a graph can be constructed that shows the magnitude (volume and peak discharge) for different probabilities. This graph can only be established once the magnitudes of several debris flows in the past have been reconstructed through a combination of stratigraphic methods, photogrammetry and dating methods. The preparation of such a graph is not part of this study.

3.4.1 Hazard Assessment

Debris flow hazard assessment is not an exact science and relies on judgement and experience as well as on empirical relationships, physics and general guidelines. Given the uncertainties involved it is prudent to be conservative. The science is, however, sufficiently developed that reasonable hazard estimates can be made. For this preliminary study, qualitative or semi-quantitative estimates (i.e. low, medium, high hazards and risks) are used rather than a purely quantitative approach, which would require significantly more funds and time.

Hazard Assessments involve field investigations to identify unstable terrain and determine the quantity of available material that may become mobilized during an event. Alternatively, one can assess the evidence on the creek fan. The assessment is complemented by historical information of **when** and **how much** material came down the creek.

For debris flows of a particular magnitude, it is possible to illustrate the varying degrees of hazard as a **hazard map** (Figure 2). Hazard delineation is based on topography and channel geometry, as well as roads and buildings that can influence flow behaviour. Preparation of a hazard map can involve computer modelling of debris flow runout. In this preliminary study hazard zones are estimated rather than modelled given the limited time and funds to complete this assignment. For this reason, the hazard map should not be used for landuse decisions but to provide a sense of the relative hazard on different sections of the creek fans.

3.5 Hazard Zones and Potential Consequences

The potential consequence from a debris flow depends on the degree of development located on the lower reaches of the creek. An area that is typically the most vulnerable is the creek fan, which is the cone-shaped depositional landform that develops as a result of repeated sediment delivery from the watershed above. The system used to classify debris flow intensity and consequence in this study is shown in Table 3 and colour-coded on Figures 2 and 3 for the 500-year design debris flow.

Table 3. Classification of Debris Flow Hazard Zones

Class	v (m/s)	d (m)	D (m)	Description
High (Red)	> 5	> 2	> 1	Direct impact with expected extensive structural damage. Severe erosion possible. Potential for loss of life inside and outside the building.
Medium (Orange)	2 - 5	0.5 - 2	0.3 - 1	Some structural damage, but mostly sediment deposition and flooding. Some erosion. Persons inside the building are considered safe. Potential for loss of life outside the building.
Low (Yellow)	< 2	< 0.5	< 0.3	Minor nuisance sediment deposition and flooding. Little erosion. No potential for loss of life inside or outside of buildings.
v is maximum flow velocity, d is maximum flow depth, and D is the maximum boulder diameter transported				

Many other elements other than houses may be subject to damage and are considered in identifying potential consequences. These may include infrastructure such as roads, bridges, telecommunication lines, hydroelectric lines, water supply conduits, storm sewers, and wastewater pipes. The present preliminary assessment, however, focuses on potential consequences on houses. Creek hazards may also result in loss of agricultural land, damage to fish and wildlife habitat that are also not included in this analysis. Table 4 summarizes the risk for three different levels of hazard and consequence.

Table 4. Risk Matrix

HAZARD PROBABILITY	CONSEQUENCE		
	High	**Medium**	**Low**
High	High	High	Medium
Medium	High	Medium	Medium
Low	Medium	Medium	Low

3.6 Acceptable Level of Risk

Comparing an existing risk to an acceptable level of risk serves to quantify the relative degree of risk. It also helps to determine the scale of mitigative measures that are necessary to reduce the risk to an acceptable level.

Ultimately, the acceptable level of risk is decided by regulatory authorities in consideration of technical evaluations and public expectations. As of this time, there is no established acceptable level of risk for creek hazards in B.C. or Canada. Therefore, there is some latitude for the choice of protective measures or solutions to minimize the risk to public safety. It should be noted, however, that work by Cave (1991) on risk acceptance has been adopted by the Fraser Valley Regional District and in part by the B.C. Ministry of Transportation. In this context, a site has to be safe for its intended use for an event occurring with a 10% probability of at least one occurrence in 50 years (475-year return period), which corresponds, to a **low** hazard probability class (Table 1).

4.0 COMMENTS ON SHORT TERM CREEK MEASURES

Beginning shortly after the events in mid October, contractors were retained to remove debris from channels that had been affected by debris flows and flood flow. This section is added because the effects of these works will likely affect long-term hazard exposure.

Photo 2 shows an example of channel works carried out on MacNab and Eng Creeks. Excavators have used the creeks' talwegs to access the channels. Accumulated channel material is excavated and placed on the channel sidewalls at slope angles between 20° and 40°. The side-casted material is neither consolidated nor armoured by riprap.

In the short-term (weeks to months) the following consequences can be expected from these works:

- decrease in debris flow hazard on the fan from existing (post event) condition due to higher channel conveyance;
- exposure of fine-grained material at the channel bottom and channel sidewalls;
- decrease in channel roughness due to removal of coarse clasts from the channel bottom and, therefore, an increase in water flow velocities which is likely partially offset by selfarmouring of coarser clasts;
- undercutting of the channel sidewalls by fluvial erosion and steepening of the banks;
- retrogressive collapse of channel sidewalls where undercut;
- a sharp increase in sediment delivery to the creek channel;
- rapid aggradation in the affected lower gradient channel sections with an associated decrease in conveyance;
- infilling of culverts and bridge crossings; and
- increase in hazard to areas adjacent to the channel by a decrease in conveyance.

The rate of the processes listed above will depend on the number and magnitude of floods in the next few months. For these reason, the channel works presently carried out at the affected creeks cannot provide sustainable protection to human development on the creek fans.

Photo 2. MacNab Ck approx. 100 m upstream of the Sylvester Road crossing. Dec. 8, 2003.

5.0 HAZARD AND RISK ASSESSMENTS

The following section describes the hazard and risk assessment based on the preliminary fieldwork and analyses conducted by BGC in December of 2003. Qualitative terms are used purposely to avoid the illusion of exactness, which cannot be provided at this overview level. More detailed assessments including test trenching, photogrammetry, dendrochronology, and the establishment of channel yield rates and point source volumes in the entire watershed are needed to better quantify debris flow magnitude and frequency and establish frequency-magnitude graphs for each creek. More detailed descriptions of how the size classes consequences and risks were determined will be included in the compendium report submitted in January of 2004.

A preliminary hazard map (Fig. 2) for the 500-year return period event is provided at a scale of 1:5000 for each creek. The hazard map is based on limited field investigation and approximations based on experience and judgement. Fan boundaries and hazard class boundaries are approximate and may change slowly over time or abruptly after a debris flow. The hazard map should therefore be viewed as a snapshot in time, rather than a long-term planning tool for which regular re-mapping would be necessary.

5.1 Field Creek

Field Creek has a watershed area of 0.34 km^2, an approximate fan area of 80,000 m^2, and an average stream angle between the fan apex and the peak elevation of its headwaters of 29°. Field Creek is considered to produce debris flow hazards and risks according to Table 5:

Table 5 - Debris flow hazard and risk assessment for Field Creek

Return Period (years)	Process	Size Class	Consequence to Virtue Property	Consequence Rating	Risk
< 20 (High)	Flood Flow	N/A	None	N/A	N/A
20 to 100 (Medium)	Debris Flow	2 (small)	Channel avulsion, direct impact of building. Potential for severe structural damage.	HIGH	HIGH
100 to 500 (Low)	Debris Flow	3 (moderate)	Channel avulsion, direct impact of buildings, deposition of over one metre of sediments at house sites. Severe structural damage expected.	HIGH	MEDIUM

Table 6 summarizes the objectives for this study, including mitigation options.

Table 6. Objectives and debris flow mitigation options for Field Creek

Objectives and Questions	Answers and Mitigation Options
• What is the risk level for different return periods at Field Creek?	• The risk level for debris flows at Field Creek is classified as high for medium return period debris flows and medium for low return period debris flows. At the present time, it is likely that during renewed debris flow activity, the Virtue residence would be impacted by debris flows.
• What is the degree of hazard for the design event (475-year return period)?	• The hazard is classified as **Medium**. The design debris flow has a high likelihood of causing structural damage to the Virtue residence.
• Has the hazard to the residence increased due to the recent debris flow?	• Probably not. The hazard persisted before the debris flow. Localized channel aggradation may have increased the hazard locally until fluvial erosion will cause channel incision to pre-debris flow conditions.
• What, if any, cost-effective mitigation measure could be implemented at Field Creek to prevent structural damage?	• A Λ-shaped engineered deflection berm could surround the buildings. Costs for such berm would likely be near or exceed the costs of the building (Fig. 2). Channel excavation will cause a temporary lowering of the existing hazard but not provide a long-term solution.

In summary, the Virtue property is located at the fringe of an active debris flow fan. Future debris flows could transport boulders of up to 1-m diameter against the house with estimated velocities of 3 m/s to 5 m/s. An event of this magnitude would likely cause severe structural damage. Deepening of the existing channel may temporarily lower the potential of avulsions on the fan; however, avulsions upstream of the modern fan apex could bypass the excavated channel section and impact the Virtue residence. A deflection berm could be constructed with a minimum height of 2.5 m and grouted riprap on the outside of the berm.

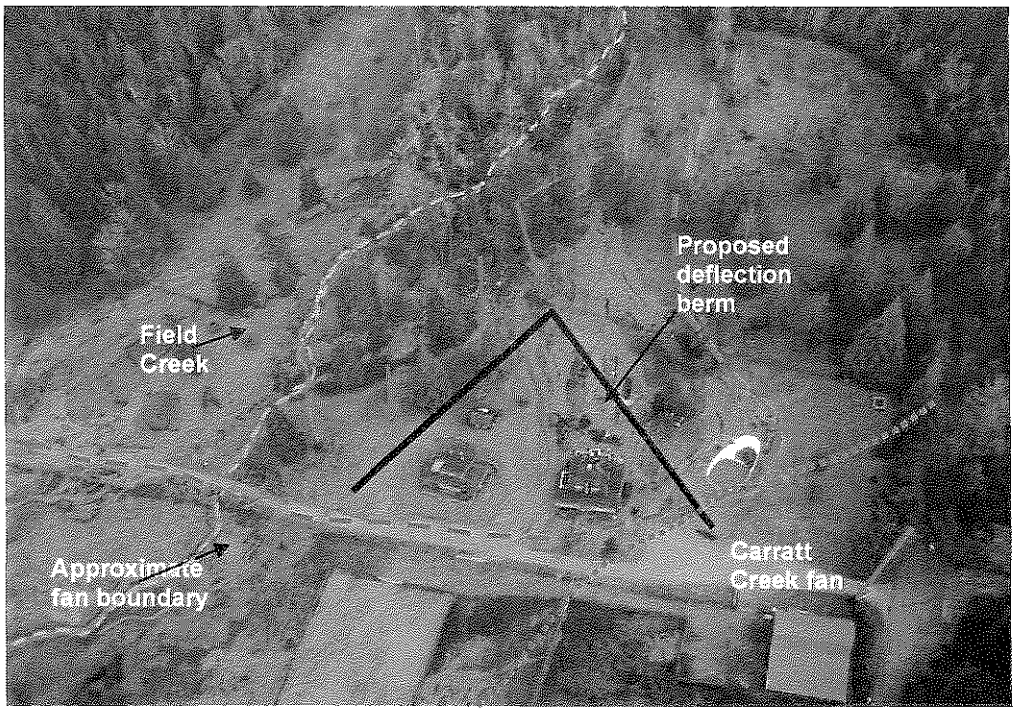

Photo 2. The Field Creek Fan and Virtue property. The blue arrows are possible avulsion routes of floodwaters and debris flows. Future debris flows from Carratt Creek may also affect the Virtue property. December 3, 2003.

6.0 ENG CREEK

Eng Creek has a watershed area of 1.35 km^2, an approximate fan area of 0.7 km^2, and an average stream angle between the fan apex and the peak elevation of its headwaters of 22°. Eng Creek is considered to produce debris flow hazards and risks according to Table 7:

Table 7. Debris flow hazard and risk assessment for Eng Creek

Return Period (years)	Process	Size Class	Consequence to Subject Properties	Consequence Rating	Risk
< 20 (High)	Debris Flow	2 (small)	Fine-grained afterflow, water and organic debris can cause nuisance flooding	LOW	MEDIUM
20 to 100 (Medium)	Debris Flow	3- (moderate)	Channel avulsion likely. Debris flows may take new channel and affect different areas of the fan than during the October 2003 event. Distant runout could cause some structural damage.	MEDIUM	MEDIUM
100 to 500 (Low)	Debris Flow	3+ (moderate)	Channel avulsion probable. Extensive debris deposition on lower fan with potential for direct impact of buildings. Severe structural damage is possible.	HIGH	MEDIUM
The + or – sign indicates that the debris flows is expected to be in the higher (+) or lower (-) range of the size class					

Table 8 summarizes the objectives for this study, including mitigation options.

Table 8. Objectives and debris flow mitigation options for Eng Creek

Objectives and Questions	Answers and Mitigation Options
• What is the risk level for different return periods at Eng creek?	• The risk level for debris flows at all properties on Eng Creek is classified as medium risk for all return period debris flows.
• Has the hazard to the residence increased due to the recent debris flow?	• Localized channel aggradation has likely increased the debris flow hazard to properties distal to the current stream channel until fluvial erosion will cause channel incision to pre-debris flow conditions.
• What, if any, cost-effective mitigation measure could be implemented at Eng Creek to prevent structural damage?	• Houses on the lower fan could be raised by at least 2 m and their upstream and lateral mound slopes should be armoured by large (> 1m diameter) angular riprap. Alternatively, Λ-shaped engineered deflection berms could surround the buildings as shown on Photo. Debris basins or debris barriers do not appear to be cost effective.

In summary, Eng Creek is an active debris-flow prone creek. Properties on the fringes of the fan are subject to debris flow impact. Low return period debris flows could transport boulders of up to 0.5 m diameter with estimated velocities of 1 to 3 m/s into the developed area. An event of this magnitude could cause structural damage. Deepening of the existing channel may temporarily lower the potential of avulsions on the fan; however, avulsions upstream of the modern fan apex could bypass the existing channel section and impact existing homes.

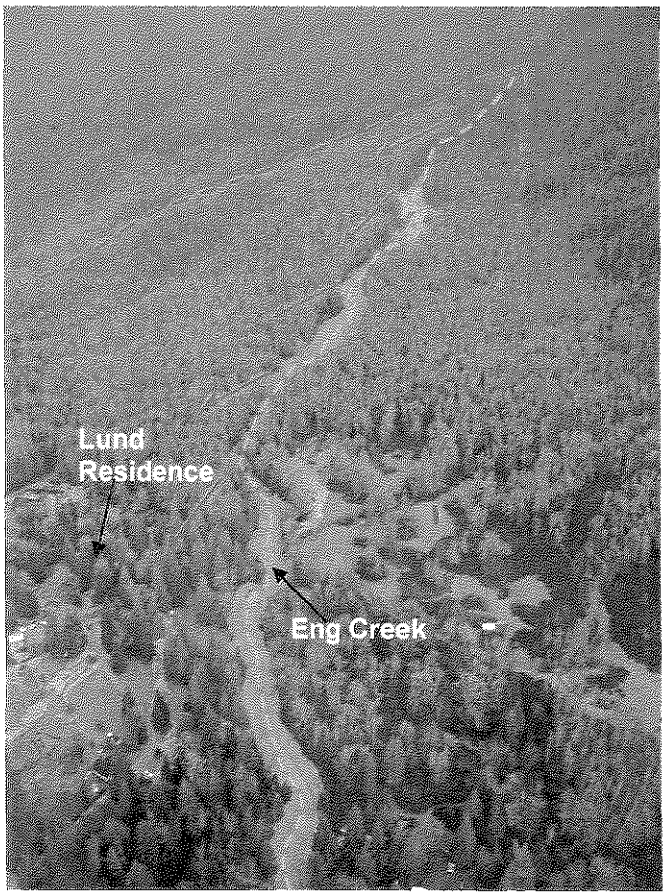

Photo 3.
Eng Creek fan. Note that the fan boundary is approximate. Blue arrows indicate possible avulsion routes. December 3, 2003.

7.0 MACNAB CREEK

MacNab Creek has a watershed area of 1.34 km^2, an approximate fan area of 0.4 km^2, and an average stream angle between the fan apex and the peak elevation of its headwaters of 25°. MacNab Creek is considered to produce debris flow hazards and risks according to Table 9.

Table 9. Debris flow hazard and risk assessment for MacNab Creek

Return Period (years)	Process	Size Class	Consequence to Subject Properties	Consequence Rating	Risk
< 20 (High)	Debris Flow	2 (small)	Fine-grained afterflow, water and organic debris can cause nuisance flooding	LOW	MEDIUM
20 to 100 (Medium)	Debris Flow	3- (moderate)	Channel avulsion likely. Debris flows may take new channel and affect different areas of the fan than during the October 2003 event. Distant runout could cause some structural damage.	MEDIUM	MEDIUM
100 to 500 (Low)	Debris Flow	3+ (moderate)	Channel avulsion probable. Extensive debris deposition on lower fan with potential for direct impact of buildings. Severe structural damage is possible.	HIGH	MEDIUM
The + or – sign indicates that the debris flows is expected to be in the higher (+) or lower (-) range of the size class					

Table 10 summarizes the objectives for this study, including mitigation options.

Table 10. Objectives and debris flow mitigation options for MacNab Creek

Objectives and Questions	Answers and Mitigation Options
• What is the risk level for different return periods at MacNab creek?	• The risk level for debris flows at all properties on MacNab Creek is classified as medium risk for all return period debris flows.
• Has the hazard to the residences increased due to the recent debris flow?	• Slightly. The recent event can be classified as flood flow rather than debris flow and deposited material on the lower part of the fan, thus decreasing the conveyance on the fan.
• What, if any, cost-effective mitigation measure could be implemented at MacNab Creek to prevent structural damage?	• Houses on the lower fan could be raised by at least 2 m and their upstream and lateral mound slopes should be armoured by large (> 1m diameter) angular riprap. Alternatively, Λ or ∩-shaped engineered deflection berms could surround the buildings as shown on Photo 3. Debris basins or debris barriers do not appear to be cost effective.

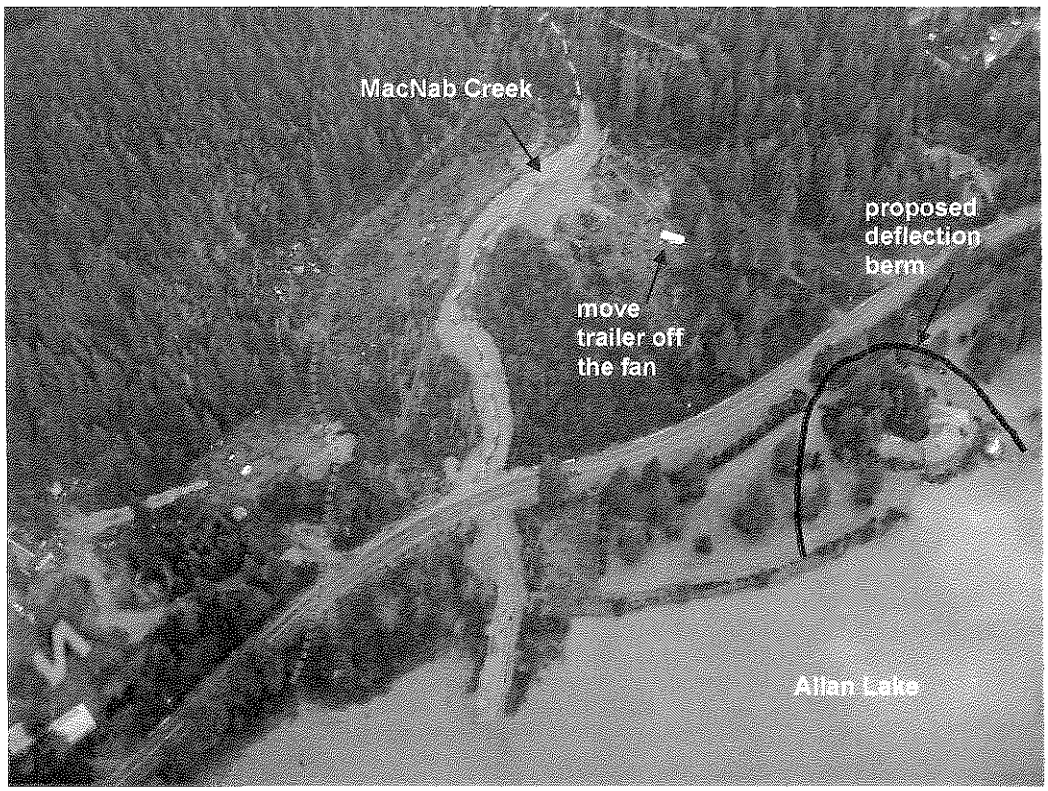

Photo 4. MacNab Creek with approximate southern fan boundary. Blue arrows indicate possible avulsion routes. December 3, 2003.

7.1 Dale Creek

Dale Creek is located on the south side of Hatzik Valley and drains the western slopes of Dewdney Peak (Figure 1). BGC traversed portions of the lower channel on December 8, 2003.

Dale Creek has a watershed area of 1.2 km^2, an approximate fan area of 0.3 km^2, and an average stream angle between the fan apex and the peak elevation of its headwaters of 26°. Dale Creek is considered to produce debris flow hazards and risks according to Table 11:

Flooding occurred at one property during the mid October 2003 rainstorm, which resulted in damage to the house. Portions of the Sylvester Road fill also collapsed and had to be repaired. Table 11 summarizes the existing hazard and risks at Dale Creek.

Table 11. Debris flow hazard and risk assessment for Dale Creek

Return Period (years)	Process	Size Class	Consequence to the 35900 Dale Road Property	Consequence Rating	Risk
< 20 (High)	Flood	N/A	A 20-year return period flood may approach the capacity of the 1500 mm diameter concrete culvert at the Sylvestor Road crossing and may exceed the flume capacity downstream of the crossing. Flooding and deposition of sands and cobbles can be expected at the subject property	LOW	MEDIUM
20 to 100 (Medium)	Debris Flood	1- (very small)	Channel avulsion likely on the fan. High likelihood that the concrete culvert will be plugged and overtopped. Floodwater, sediment and organic debris will likely cause considerable damage to the subject property.	MEDIUM	MEDIUM
100 to 500 (Low)	Debris Flow	3 (moderate)	Channel avulsion probable. Extensive debris deposition on lower fan possible if single channel flow occurs with potential for direct impact of buildings. Structural damage is possible.	HIGH	MEDIUM

Table 12 summarizes the objectives for this study, including mitigation options.

Table 12. Objectives and debris flow mitigation options for Dale Creek

Objectives and Questions	Answers and Mitigation Options
• What is the risk level for different return periods at Dale creek?	• The risk level for low, medium and high return period debris flows is classified as **Medium**
• Has the hazard to the residences on the fan increased due to the recent event?	• Slightly. The recent event can be classified as flood flow rather than debris flow and deposited material in the channel, thus decreasing the conveyance on the fan and providing readily erodible material for further transport.
• What, if any, cost-effective mitigation measure could be implemented	• The most cost-effective solution may be to acquire the home and relocate it to a safer location.

7.2 Carratt Creek

Carratt Creek has a watershed area of 2.5 km^2, an approximate fan area of 0.4 km^2, and an average stream angle between the fan apex and the peak elevation of its headwaters of 26°. Carratt Creek is considered to produce debris flow hazards and risks according to Table 13.

A debris flow occurred on October 16, 2003, which caused a bypassing or overtopping of the northern dyke and flooding on the Virtue property. Large amounts of sediment were deposited in the channel of Carratt Creek between the two confining berms.

Table 13. Debris flow hazard and risk assessment for Carratt Creek

Return Period (years)	Process	Size Class	Consequence to Fan Properties	Consequence Rating	Risk
< 20 (High)	Debris Flow	2 (small)	Debris flows would likely not overtop the southern dyke but would likely continue to flow towards the North and may affect the Virtue property.	LOW	MEDIUM
20 to 100 (Medium)	Debris Flow	3 (moderate)	Debris flows could overtop the southern dyke and affect large portions of the fan as shown on Fig. 2. Structural damage can be expected in the direct impact zone.	HIGH	HIGH
100 to 500 (Low)	Debris Flow	4 (large)	Multiple failures in the watershed would produce a large debris flow that would likely affect the majority of Carratt Creek fan. Complete destruction of houses on the fan is possible.	HIGH	MEDIUM

Table 14 summarizes the objectives for this study, including mitigation options.

Table 14. Objectives and debris flow mitigation options for Carratt Creek

Objectives and Questions	Answers and Mitigation Options
• What is the risk level for different return periods at Carratt Creek?	• The risk level for low, and high return period debris flows is classified as **medium** and for the medium return period as **high**.
• Has the hazard to the residences on the fan increased due to the recent event?	• Yes. The recent event has deposited large amounts of material in the channel and has bypassed the southern berm protecting the Virtue property. Channel conveyance is likely significantly decreased compared to the pre-debris flow condition.
• What, if any, cost-effective mitigation measure could be implemented	• Both the southern and northern dyke could be constructed higher. This, however, will cause a long-lasting maintenance issue since the channel between the dykes will aggrade rapidly over time. • Properties on the fan could be protected by Λ or ∩-shaped engineered deflection berms. • Debris basins or debris barriers would likely cost several million dollars and my therefore not be cost effective.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Ample evidence of past debris flows was encountered in the field. Logging in the upper watersheds has likely increased debris flow frequency and possibly magnitude in all affected watersheds.

Short-term measures implemented in December of 2003 include culvert clearing, stream channel excavation on the fans and removal of excess material deposited on the fans and roads. Stream channel excavations will likely lead to quick aggradation of the low-gradient channel sections and, if not maintained return the hazard to pre-debris flow conditions.

At the present time, despite short term measures carried out by the B.C. Ministry of Transportation, significant hazards, particularly for low frequency, high magnitude debris flows persist for all investigated creeks. The above hazard and risk assessment is largely qualitative and relies heavily on BGC's experience and judgement. If development is to continue in the area between Sylvester Road and the west-facing slopes of Hatzik Valley or if active or passive mitigation debris flow measures are considered, detailed studies for each affected creek channel are recommended.

We trust that the information provided herein fulfills your present requirements.

Yours sincerely,
BGC Engineering Inc.
Per:

Matthias Jakob, Ph.D., P.Geo., P.G.
Senior Geoscientist

Reviewed by:

K. Wayne Savigny, Ph.D., P.Eng., P.Geo.
Vice-President